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LASER SAFETY PROGRAM REVIEW PANEL

A REPORT TO THE DEPARTMENT OF ENERGY AND THE LAWRENCE BERKELEY NATIONAL LABORATORY

JULY 28, 2003

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EXECUTIVE SUMMARY

On March 14, 2003, a University of California-Berkeley (UCB) graduate student received an ocular injury when overexposed to laser radiation while performing Department of Energy (DOE) /Lawrence Berkeley National Laboratory (LBNL) sponsored research in UCB space. This accidental exposure precipitated the establishment of a panel to review the laser safety program at the LBNL and for the UCB laser safety program where laser use is funded by LBNL or the DOE. The panel was charged with determining the adequacy of the existing laser safety programs using the *ANSI Z136.1 Standard for the Safe Use of Lasers* and LBNL's Integrated Safety Management (ISM) System as a foundation. The written laser safety programs and other key LBNL and UCB documents were reviewed as were laser research areas.

The Panel included representatives from LBNL, UCB, DOE, and the private sector, as well as observers from two sister national laboratories. The panel met for three days from May 28 through May 30, 2003. The first two days included presentations, interviews and tours of laser labs at LBNL and UCB. The third day was a panel work session.

The Panel visited three laboratories at LBNL and two laboratories at UCB. Based upon on-site observations and review sessions, the two laser safety programs were compared using LBNL's ISM program, although UCB has not adopted ISM since the campus is not a DOE facility.

Concerning the fundamental question about successful implementation of ANSI Z136.1, the general answer is "yes." Both programs are based upon the recommendations in ANSI Z136.1 and have implemented significant sections of the standard.

The findings of the Panel are positive, negative or neutral in nature. In total, there were twenty-two specific findings and thirteen recommendations for program improvement at LBNL. Seventeen of the findings were in two laboratories and five were general in nature. For the UC-Berkeley program, there were twenty-five laboratory-specific and nine general findings, with twenty-two recommendations for program improvement.

The most consistent findings and hence, recommendations, deal with beam alignment, entryway controls, and protective eyewear. Accident data collected from around the world has shown that beam alignment is responsible for most laser-induced injuries in laboratories. In fact, the injury that precipitated this review occurred when the user removed his eyewear when he thought the alignment complete, exposing himself to a stray beam.

Protective eyewear is another important control measure. The Panel observed many basic problems with eyewear including improper storage, possible wavelength incompatibility, questions about the suitability of the optical density, and lack of inspection.

I. INTRODUCTION

On March 14, 2003, a University of California-Berkeley (UCB) graduate student received an ocular injury when overexposed to laser radiation while performing Department of Energy (DOE) /Lawrence Berkeley National Laboratory (LBNL) sponsored research in UCB space. This occurred during an external alignment of benchtop optics with a pulsed, infrared laser beam. The student thought the alignment task was completed, and was not wearing laser protective eyewear when injured by a specular reflection of the beam (stray beam) from an optic located prior to the terminal beam dump. Apparently, the optic had been located at this position in an earlier experiment by one of four groups of graduate students who share this laser system.

This accidental exposure precipitated the establishment of a panel to review the laser safety program at the LBNL and for the UCB laser safety program where laser use is funded by LBNL or the DOE. The panel was charged with determining the adequacy of the existing laser safety programs using the *ANSI Z136.1 Standard for the Safe Use of Lasers* and LBNL's Integrated Safety Management (ISM) System as a foundation. The written laser safety programs and other key LBNL and UCB documents were reviewed as were laser research areas.

The objective of the Laser Safety Program Review Panel is stated below.

> "The panel is convened to provide a comprehensive review of the LBNL Laser Safety program for all on-site operations as well as the UCB laser safety program to the extent that it affects LBNL laser operations on the University of California Berkeley campus. There are two objectives for this review: (1) to determine whether a consistent and effective approach to work planning, hazards analysis and controls exists for DOE sponsored work at LBNL and the UCB campus; and (2) to provide recommendations for program improvements so that laser accidents are prevented and the safe conduct of scientific research that uses lasers is optimized."

[Note: The following information on the language used in this report dealing with laser certification and usage may be useful to some readers. Certification of laser products is a regulatory requirement promulgated through the U.S. Food and Drug Administration in 21 CFR Subchapter J and applies to laser product manufacturers. Laser safety in the user's environment is addressed in the *American National Standard for the Safety User of Lasers*, Z136.1-2000. This document is a consensus standard of recognized good practices and has no requirements for certification of laser products.

The FDA regulations require the laser product manufacturer to classify then certify the laser or laser system to the class-dependent requirements of the regulations. The classification scheme used by the FDA identifies the various laser classes by Roman numerals. The classification scheme used in Z136.1-2000 is not identical to the FDA scheme, in numerous ways. One of these differences is that ANSI uses Arabic numbers to identify its classes.

Hence, in this report Roman numerals are used to identify the class of a laser product (e.g., Class IIIb or IV). When classes are identified by Arabic numbers, it will refer to the users' environment or laboratory. An example of this is: total enclosure of the beam path of a Class IV laser will produce a Class 1 work environment.]

A. Integrated Safety Management

The Department of Energy (DOE) safety program provides a formal, organized process whereby people plan, perform, assess, and improve the safe conduct of work. The Integrated Safety Management System is institutionalized through DOE directives and contracts to establish the Department-wide safety management objective, guiding principles, and functions. The system encompasses all levels of activities and documentation related to safety management throughout the DOE complex.

The LBNL is a DOE facility managed and operated by the University of California under contract with the DOE (DE-AC03-76SF00098, modification M372). The contact for the management and operation of the LBNL includes the key ISM performance expectations through the various clauses and directives. Contract Clause 6.7 – DEAR 970.5204-2 Integration of Environment, Safety and Health into Planning and Execution (June, 1997), section (h) specifically states the responsibility for ensuring compliance with the EH&S requirements applicable to this contract at the facilities identified in Clause 6.1, Laboratory Facilities, regardless of the performer of the work. Previous DOE reviews resulted in the approval of the LBNL Safety Management Description (June, 1998) and verified LBNL had adequately implemented the described approach in September of 2000.

LBNL's safety management approach tailors the controls based on the specific hazards associated with the work through the processes established for work authorization classification. The three work authorization classifications are: 1) Line Management, 2) Formal, and 3) Facility-Based. Routine activities with minimal hazards, including work with up to Class IIIa lasers, are informally authorized by the Division Line Management. Formal work authorizations utilize the Activity Hazard Document (AHD) as the primary tool for identifying the hazards and specifying controls necessary for work authorization. Class IIIb and IV lasers require formal work authorization.

The Panel used the seven guiding principles and five core functions of ISM to evaluate the LBNL laser safety program. Although UCB is not required to implement ISM, the UCB laser safety program was also compared to the guiding principles and core functions to allow for a comparison of implementation methods between the facilities.

The seven guiding principles are:

1. Line management is responsible for EH&S concerns.
2. Clear roles and responsibilities for ensuring EH&S must be established.
3. Personnel must possess competence commensurate with responsibilities.

4. Priorities must be balanced between EH&S, programmatic and operational considerations at the institution.
5. Hazards must be identified and safety standards and requirements established before work is performed.
6. Administrative and engineering controls must be tailored to the work being performed.
7. Conditions and requirements for operations to be authorized must be established and agreed upon.

The guiding principles are implemented through the five core functions, which are listed below:

1. Work planning.
2. Hazard and risk analysis.
3. Establishment of controls.
4. Work performance.
5. Feedback and improvement.

At LBNL, the ISM System is documented in the *Integrated Environment, Health & Safety Management Plan* (October 2001, Revision 2). This document describes the core functions at the institutional, division/department level, and project or activity level, as well as addressing the management of contractor, visitor and guest activities. It includes a number of appendices including the current "Memorandum of Understanding Between UCB and LBNL Concerning Environment, Health and Safety Policy and Procedures," which will be referred to as the MOU. As stated previously, environment, health and safety processes and practices at UCB do not fall under the DOE ISM program, however they are regulated by the California Occupational Safety and Health program.

B. MEMORANDUM OF UNDERSTANDING

LBNL has tailored their safety management approach with consideration of the unique aspects associated with the property lease provisions established by the contract (Appendix I) and the collocation with UCB. A Memorandum of Understanding (MOU) between LBNL and UCB, dated June 23, 1993, stipulates the locations where LBNL activities need to conform to LBNL's EH&S programs or UCB's EH&S programs.

The MOU defines occupied space and establishes authority and EH&S requirements in the space. There are two defined DOE spaces on campus, the Donner and Melvin Calvin Laboratories. These buildings shared by LBNL and UCB personnel. However, the buildings are treated as part of LBNL and LBNL is responsible for EH&S concerns. The other space is called Appendix I space, although the current MOU defines this space as Appendix J space. Appendix I space is either on the main UCB campus or the Richmond Field Stations. The UCB faculty are responsible for EH&S concerns in this space with UCB EH&S staff providing oversight and compliance support functions Work performed in Appendix I space is to be conducted in accordance with UCB policies and procedures.

Some individuals have dual appointments and perform research at both LBNL and in UCB Appendix I space. Per the MOU, the EH&S procedures these individuals follow depend on the location of the work.

[Note: Appendix I space is located on the main UCB campus and at the Richmond Field Stations, but does not include Donner and Melvin Calvin Laboratories. Appendix I space is not leased to DOE or LBNL.]

C. PANEL BUSINESS

The panel consisted of the following members: Roger Christensen of the DOE Richland Field Office, Tim Hitchcock of LightRay Consulting (chairman of the Panel), Paul Lavely of the UCB EH&S Department, Donald Lucas of LBNL and UCB, and Frank Svec of UCB and LBNL. The laser safety officers (LSO) from Los Alamos National Lab (LANL) and Lawrence Livermore National Lab (LLNL), David Dixson and David Taylor, respectively, were observers. The panel staff was John Seabury of the LBNL EH&S Department, who was assisted by Ms. Jann Jackson of LBNL.

The panel met for three days from May 28 through May 30, 2003. The first two days included presentations, interviews and tours of laser labs at LBNL and UCB. The third day was a panel work session.

Presentations were provided by the following individuals:
Hattie Carwell, DOE Berkeley Site Office
Robin Wendt, Deputy-Division Director, LBNL EH&S
Mark Freiberg, Director, UCB EH&S
Jeffrey Chung, LBNL EH&S
Ross Fisher, LBNL EH&S
Ted de Castro, LBNL LSO and
Eddie Ciprazo, UCB LSO.

Interviews were given by:
Luning Zhang, UCB graduate student who suffered laser injury and
Ron Shen, a UCB Physics Professor and a LBNL Principal Investigator (PI), responsible for the lab in which Mr. Zhang was working when injured.

Laboratory tours involved the following space at LBNL:
2-333 Ultrafast Photoelectron Spectroscopy
Beam Lines 9.0.2 and 9.0.3 at the Advanced Light Source, Chemical Dynamics, and
71-256 complex and 71-146B/146L, Wakefield Accelerator.

Lab tours at UC-Berkeley included:
Hildebrand B71 and
Birge Hall 145.

Presenters and interviewees were questioned to help panel members better understand both the documented and implemented laser safety programs. Panel members reviewed the written laser safety programs and other key documentation for both institutions. During the tours, the laboratories were examined to determine their conformance to the ANSI Z136.1-2000 standard. Specific findings by laboratory are documented in the Section III of this report on conformance with ANSI Z136.1-2000.

II. FINDINGS: THE ISM FOUNDATION

Following the presentations, interviews and tours, the panel met and reviewed both the laser safety program at LBNL and the part of the laser safety program at UCB that oversees research funded by LBNL. The review included an evaluation of the seven guiding principles and five core functions for both programs. The findings are compiled in Tables 1 and 2.

Table 1 - Comparison of Laser Safety Programs using the Seven Guiding Principles of the ISM System

Seven Guiding Principles	*LBNL work performed at*	
	LBNL	UCB
Line Management Responsibility for EH&S. (See Section II-A)	• Line Management Responsibility is clear for work performed in LBNL spaces.	• LBNL does not exercise line management of work performed in Appendix I spaces. • Laser safety line management responsibility is designated in the UCB "Laser Safety Manual" to the PI. However implementation may vary at the level of each research group. • Overall safety responsibilities are spelled out in "Responsibility for Environment, Health and Safety" (University of California, September, 1995; http://www.ehs.berkeley.edu/policy/responsib/respdoc.html), herein referred to as the Responsibility for Environment, Health and Safety Document. However, PIs and users interviewed were not aware of this Policy or

		their responsibilities as outlined in the Document.
Clear Roles and Responsibilities (See Section II-B)	• LBNL requirements for the safety of off-site operations is addressed in Section 5.5 of PUB-3000. This document requires additional safety documentation unless the work is performed in Appendix I space. • The AHD process recognizes the specific hazards associated with work with lasers. • Chapter 16 of PUB-3000 states that the LBNL program is based on ANSI Z136.1, specifies the LSO, and addresses some specific responsibilities of the LSO including training, medical surveillance, and protective equipment.	• LBNL's ISM systems do not apply in Appendix I space, because the MOU predates ISM by 5 years. [Note: The MOU was included as an appendix to LBNL's DOE-validated ISM program, thus the exclusion of Appendix I space is in accordance with the ISM plan. • There is uncertainty at the LBNL Division Management Level as to the responsibility for operations in Appendix I space. • Some UCB PIs express concern that operations in Appendix I space might be subject to both LBNL and UCB rules or safety systems. • The "Laser Safety Manual" states that the program is based on ANSI Z136.1, has designated a LSO, and addresses some specific responsibilities of the LSO including: LSO, training, medical exams, audits, and posting.
Competence Commensurate with Responsibilities (See Section II-C)	• LSO: good. • PI's: good. • Activity Supervisor: good but needs to be specifically called out in Chapter 16 of PUB-3000 by name, and used consistently in Chapter 6 of PUB-3000 (versus work leader). • Individual user: level of training is reasonable for their responsibility.	• LSO: good. • PI's: those contacted during this survey were good, but the Panel heard reports of variable competency. • Laboratory laser safety person: level of competency and qualifications vary due to unclear and undocumented responsibilities for the position. • Individual user: level of training is reasonable for their responsibility, but the results of "read and sign" training can be

		inconsistent.
Balanced Priorities: on the grand scale, are the hazards of lasers being appropriately addressed? (See Section II-D)	• Some personal protective equipment (PPE) and engineering controls are not systematically implemented across the lab.	• EH&S resources appear to be challenged as indicated by timeliness of inspections. • At the PI level, resources are available for safety equipment although it is often necessary to request the resources from funding agencies through the budgetary planning forms. • Engineering controls are not systematically implemented across the campus.
Identification of EH&S Standards and Requirements (See Section II-E)	• ANSI Z136.1 is identified as the applicable standard. • In general, the laser safety program is in compliance with this standard. • LBNL has specifically excluded section 3.4.1 (nominal hazard zones) of the ANSI Z136.1-1993 standard from their requirements. This is not the most current version of the Z136.1 standard.	• ANSI Z136.1 is identified as the applicable standard. • In general, the laser safety program is in compliance with this standard. • As will be reviewed under the heading of "findings" later in the report, some aspects of the UCB program do not fully conform to the ANSI Z136.1 standard.
Hazard Controls Tailored to Work Being Performed (See Section II-F)	• Postings and special safety procedures for beam alignment are inconsistently distinguished from those for operations (i.e., some AHDs are better than others). • Beam control and/or PPE is not consistently applied. • LBNL has a policy of total beam enclosure or eyewear for Class IIIb and IV lasers.	• Postings and special safety procedures for beam alignment do not distinguish between alignment and normal operations. • Need for beam control and/or PPE is not consistently analyzed. • UCB places priority on engineering controls over administrative controls.
Operations Authorization (See Section II-G)	• Yes, through the AHD.	• Yes, for process startup, through the Laser Use Registration (LUR) document, but process changes can be made prior to the LUR being updated. PIs are to notify

		the LSO if the LUR needs modification.

The findings for the ISM Guiding Principles from Table 1 are discussed in Sections IIA through IIG, below.

A. LINE MANAGEMENT RESPONSIBILITY FOR EH&S

LBNL – The employees are trained on ISM. The documented ISM program includes responsibility at the institutional, divisional, and departmental level, and activity centers. Hence, the Panel concluded that line management responsibility is clearly stated and understood in LBNL space.

UC-Berkeley - ISM has not been adopted on the UC campuses, although the UC system is considering adopting a similar—but not identical--system. Thus, UCB employees and students do not receive training on the ISM system. However, faculty, students and staff with dual appointments in both institutions do receive ISM training.

The contract between LBNL and UCB describes space assignments in campus buildings as well as other requirements. Government area is addressed in Appendix I of the contract and, per the contract, is effectively government property for the period of the agreement. This includes two locations on campus, Donner and Melvin Calvin Laboratories.

At UCB, laser safety line management responsibility is designated in the "Laser Safety Manual" and in the Responsibility for Environment, Health and Safety Document. Both documents specify the campus PI as the key individual, but interviews with two campus PIs indicated that it is not clear who is line management, because some campus faculty do not consider themselves line management, especially for safety issues. During the review sessions, the topic of who are managers at UCB was addressed by Panel Members P. Lavely, D. Lucas and F. Svec, as well as PIs during laboratory reviews. Discussion dealt with how line management safety responsibilities are implemented on campus. All agreed that line management responsibility for safety could not be re-delegated by the PI; however, in many cases implementation falls to an individual in the laboratory assigned to be the laboratory laser safety person.

The laboratory laser safety person is typically a graduate student who is assigned laser safety and training duties, as well as other laboratory and safety duties. The determination of who is selected and what duties are assigned is not clear, but it does not appear to be related to an interest or desire in laboratory safety. One of the two laboratory laser safety contacts interviewed stated that he had received no training beyond that of his peers, and did not appear to be aware of or prepared to perform these duties.

The assignment of responsibilities from the university administration to the student is clear. This is detailed in the Responsibility Document. Specific laser safety responsibilities are found in the "Laser Safety Manual" and are included in the training module. However, the local implementation for laser safety at the laboratory level does not appear to be consistent. This occurs due to the informal delegation of duties and training of the laboratory laser safety person.

At UCB, responsibilities for environment, health and safety are assigned in the Responsibility for Environment, Health and Safety Document. This is an institutional policy that addresses the responsibilities of individuals, management, administrators and managers, EH&S, and faculty oversight committees. However, none of the PIs, staff, or graduate students who were interviewed by the Panel were aware of the Responsibility Document.

B. Clear Roles and Responsibilities

LBNL – The researchers sometimes work at locations other than LBNL proper or the UCB campus, (e.g., other national laboratories, industrial locations, or the Hanford Site). According to Panel member R. Christensen, this includes the use of lasers. The LBNL safety management system provides direction on procedures, systems and mechanisms to assure that work is performed safely at LBNL, including off-site work. Safety for work not performed at LBNL is addressed in Chapter 5.5 of the "Health and Safety Manual," "Off-Site Safety." This Chapter specifically excludes work performed in Appendix I (J) space from certain requirements, specifically for submission and approval of "Additional documentation required by LBNL ... ."

High-level documents do not mention laser safety specifically. It is implied by way of the Activity Hazard Document (AHD), which is the first level of documentation which specifically mentions lasers as an identifiable hazard. The AHD is a formal authorization required for increased hazards and is the responsibility of the work leader. Chapter 6 of PUB-3000 states that "the principal investigator, supervisor, or manager (work leader) needs to document the work and associated hazards, describe administrative and engineering controls to mitigate those hazards, and document training or certification for the participants in a written document or plan." Chapter 16 of PUB-3000 states that AHDs for Class IIIb and IV lasers must be approved and reviewed annually. Hence, the AHD process recognizes the specific hazards associated with these lasers.

LBNL uses the ANSI Z136.1 standard to establish its laser safety program. Specific responsibilities of laser users, LBNL PIs and laser supervisors, and the LSO are listed in Chapter 16 of PUB-3000. The Panel performed a review of three laser-use laboratories. In general, the laboratories are in conformance with the standard. Items of possible nonconformance or of questionable safety practices were identified. These are addressed below in section of this report on conformance with the ANSI Z136.1-2000 standard.

UC-Berkeley - Although the current MOU was written before DOE implemented the ISM policy, the MOU specifies that LBNL safety systems do not apply in Appendix I (J) space and designates UCB safety systems as applicable.

According to the LBNL ISM written program, each division/department "that must develop and implement an ISM (EH&S) plan performs an annual review and signoff by the division director/department head to ensure that the plan is current and addresses its EH&S program/operational needs." In addition to the annual review, which is in the form of a self-assessment, EH&S Integrated Functional Appraisals (IFA) are carried out at the division or project level, as well as other reviews (e.g., MESH reviews). However, this is only applied to LBNL and not for work at UCB that is funded by LBNL. Based on this, the Panel concluded that there is uncertainty at the LBNL division management level concerning the responsibility for operations in Appendix I spaces.

Many PIs at UCB are associated with LBNL and are, therefore, familiar with the rules and requirements of both LBNL and UCB safety management systems. While performing laboratory reviews at UCB, at least one PI expressed the concern that operations in his laboratory, an Appendix I space, could be subject to safety requirements for both organizations.

The UCB "Laser Safety Manual" identifies the ANSI Z136.1 standard as the basis for its program. Many of the specific responsibilities of the LSO are included in the manual, as well as responsibilities of Department Chairpersons, UCB PIs, and users. A review was performed of two laser-use laboratories at the campus. In general, the laboratories are in conformance with the standard. Items of possible nonconformance or of questionable safety practices were identified. These are addressed in Section III of this report, dealing with conformance with the ANSI Z136.1-2000 standard.

C. Competence Commensurate with Responsibilities

LBNL - The laser safety officer (LSO) is a long-time employee of the laboratory who has worked in radiation protection while in EH&S. He is a Certified Laser Safety Officer through the Board of Laser Safety. This indicates a level of understanding of laser safety that is commensurate with a high degree of laser hazard (i.e., Class IIIb and IV lasers).

PI's have received laser safety training by taking the LBNL laser safety course, EHS0280, and receive retraining every three years. The responsibilities of PIs and laser supervisors are listed in Chapter 16 of PUB-3000, "Lasers." Two of the Panel members are PIs at the lab as noted earlier. Both demonstrated a good practical knowledge of laser safety.

The Activity Supervisor is defined in Appendices E and F of Chapter 6 of PUB-3000 as the "person having authority to designate operators of equipment." The work leader is defined in Appendix D of Chapter 6 as a LBNL PI or responsible supervisor. However, neither term is used in Chapter 16 of PUB-3000.

Individual users must take the laser safety course, EHS0280, and be familiar with the Activity Hazard Document. The Panel concluded that the level of training is reasonable for their responsibility.

UC-Berkeley - The laser safety officer is a Certified Laser Safety Officer through the Board of Laser Safety. This indicates a level of understanding of laser safety that is commensurate with a high degree of laser hazard, i.e., Class IIIb and IV lasers.

PIs must read the UCB "Laser Safety Manual," the "Laser Safety Training Supplement," take a self-test, and submit this to the LSO. The PI is responsible for completing the Laser Use Registration (LUR). Four UCB PIs, three with dual appointments, were contacted during this review. These contacts stated that PIs with dual appointments take both LBNL and UCB laser safety training. All exhibited a good understanding of laser safety and safety requirements. However, Panel members noted that there are reports of variable competency of PIs with regards to laser safety program implementation.

Laboratory laser safety persons are assigned laser safety implementation duties by the PI. The level of competency and the qualifications of the laboratory laser safety person vary due to unclear and undocumented duties for this position. One of two laboratory laser safety persons interviewed stated that he has only received training on laser safety comparable to his peers in the lab (i.e., no additional training other than that prescribed by UCB for all laser users).

Individual users must read the UCB "Laser Safety Manual," the "Laser Safety Training Supplement," the Laser Use Registration, take a self-test, sign a certificate and submit the quiz and certificate to the LSO. The level of training is reasonable for their responsibility, but handbook training can be inconsistent. UCB is considering an update to the training materials and methods.

D. BALANCED PRIORITIES

On the grand scale, the hazards associated with lasers are being addressed at LBNL and UCB. The programs have LSOs, written programs, training, medical evaluation, and knowledgeable users.

LBNL – During the laboratory reviews it was noted that some laser safety protective eyewear and some control measures are not systematically implemented. For example, in the ALS Beam Line, standard safety protective eyewear was available for use with an excimer laser. [This is one of a family of gas lasers that produce ultraviolet (UV) radiation.] The eyewear was not marked with optical density or wavelength as specified in ANSI Z136.1-2000. Most likely, the eyewear is polycarbonate and will be useful in attenuation of UV radiation, although the extent of attenuation is not known, unless tested. In the same experiment, the researchers had appropriately marked laser protective eyewear for a frequency-doubled YAG laser operating at 532 nanometers (nm).

A second inconsistency at the ALS Beam Line was that there were two different curtains surrounding the bench for the excimer laser. One curtain was made of a polymer that did not appear to be a laser protective material. This curtain was substantially torn near a gas cabinet that was located on a main aisle. A second curtain was a heavy-duty laser protective curtain that included a sign pocket.

UC-Berkeley - According to the UCB LSO, all Class IIIb and IV lasers are to be audited annually. Until 2002, campus lasers were being audited annually. However, UCB is far behind in meeting this goal for 2003. This appears to be due to insufficient human resources to perform the audits.

Laboratories that were visited had many basic laser safety items such as laser protective eyewear, laser warning signs, viewing cards, and warning lights. According to Panel member, F. Svec, PIs may not have sufficient resources available for safety equipment. If this is the case they may use resources designated by the funding agencies for research or specify safety equipment in budgetary planning of projects.

Engineering controls, as recommended in ANSI Z136.1-2000, are not systematically implemented in laser laboratories across the campus. In some laboratories, as much of the beam as is practical is enclosed; in other labs, this is not the case. This is reviewed in more detail in the Section III of this report.

E. IDENTIFICATION OF EH&S STANDARDS AND REQUIREMENTS

LBNL - The *American National Standard for the Safe Use of Lasers*, ANSI Z136.1, is identified as the applicable standard in Chapter 16 of PUB-3000.

According to LBNL personnel, one section of the 1993 edition of ANSI Z136.1 has been excluded from LBNL's compliance scheme. This was cited as section 3.4.1, which was believed to be the requirement for "panic buttons" in Class 4 laser controlled areas. Upon checking this paragraph in the 1993 standard, it was determined that it was the section on determination of nominal hazard zones (NHZs). According to Panel Staff, J. Seabury, this decision was made by the previous LSO on the basis that determination of the NHZ is unnecessary because it will usually be much larger than the laboratories where Class IIIb and IV lasers are used. As will be reviewed in the section on conformance with ANSI Z136.1-2000, the standard requires both the determination of NHZs and the utilization of panic buttons.

UC-Berkeley - The *American National Standard for the Safe Use of Lasers*, ANSI Z136.1, is identified as the applicable standard in the "Laser Safety Manual."

F. HAZARD CONTROLS TAILORED TO WORK BEING PERFORMED

LBNL - During the laboratory reviews, questions were asked of laser users about precautions taken during beam alignment and documentation of alignment procedures. From this it was determined that postings and special safety procedures for beam alignment are inconsistently distinguished from those for operations. This is discussed in more detail below in the section on conformance with ANSI Z136.1-2000.

In one laser use area, lasers with visible and UV beams were used. Protective eyewear labeled with wavelength and optical density were available for the visible beam laser. However, for the UV laser, protective eyewear was available that was not labeled with the necessary information on wavelength and optical density. In the same area, a welding curtain and a laser curtain were used as a barrier around the bench for the UV laser. A general observation from LBNL EH&S personnel is that some installations at LBNL have done a more thorough job of enclosing the beam path than have others with similar situations. This lead the panel to conclude that beam control and/or PPE is not consistently applied. This item will be discussed in more detail below in the section of this report on conformance with the ANSI standard.

The laboratory has a policy of total beam enclosure or eyewear for Class IIIb and IV lasers.

UC-Berkeley - During the laboratory review, questions were asked of laser users concerning precautions taken during beam alignment and documentation of alignment procedures. From these it was determined that postings and special safety procedures for beam alignment are inconsistently distinguished from those for operations. This is discussed in more detail below in Section III of this report.

In a discussion following the laboratory reviews, the Panel concluded that beam control measures are not consistently applied in the laser labs. Specifically, this item deals with beam enclosure. Also, it appears to be necessary to analyze the steps in alignment procedures where it is necessary to wear laser protective eyewear. Because beam alignment is probably the single most hazardous function to perform with a laser, it is necessary that analysis and documentation be consistently applied.

Following the Panel Review, the UCB Non-ionizing Radiation Safety committee (NIRSC) met and addressed control measures. They affirmed that the priority is for engineering controls and that the LSO will review each of the campus Class IIIb and IV lasers to assure that adequate engineering controls are being used and, if not, the LSO is to "provide guidance on the needed controls," as reported by Panel member P. Lavely.

G. OPERATIONS AUTHORIZATION

LBNL - This is handled through the AHD as specified in Chapters 6 (Work Authorization) and 16 (Lasers) of PUB-3000. AHDs were examined for three laboratories and found to be relatively complete, with the exception of information on alignment procedures and the use of high, optical density protective eyewear to view low-power beams during alignment.

UC-Berkeley – Operation authorization is handled through the LUR document. The LUR is required for laser start-up and users are required to read the LUR for their laser process. The PI is required to notify the LSO of significant changes to the laser system. However, if changes are made to the laser system or process before the annual review and the PI does not notify the LSO, the LUR may not indicate the actual system in use nor the true hazard. LURs were reviewed for two PIs and the laboratories under their control.

Table 2 - Comparison of Laser Safety Programs using the Five Core Functions

Five Core Functions	*LBNL work performed at*	
	LBNL	UCB
Work Planning (See Section II-H)	• Adequate.	• LBNL does not have systematic feedback on laser safety on campus.
Hazard and Risk Analysis (See Section II-I)	• Through AHD process, emphasizing that work leader does the analysis with EH&S guidance. • Documentation of periodic inspections of laser labs are not available.	• Through LUR process, PI and EH&S do the analysis together. • Audit records were available except for the past year.
Establishment of Controls (See Section II-J)	• AHD establishes the controls. • Beams must be enclosed or protective eyewear must be worn. • Eye examinations exceed industry standards.	• LUR establishes the controls. • UCB-NIRSC has recently adopted a policy of priority for engineering controls and total review of Class IIIb and IV lasers by the LSO. • Eye examinations exceed industry standards.
Perform Work within Controls (See Section II-K)	• Adequate. • Annual reviews document conformance, but historical records are not accessible.	• Adequate. • Annual LSO reviews document conformance, although these have been suspended recently.
Continuous Feedback and Improve (See Section II-L)	• Annual AHD review cycle provides feedback. • Additional feedback through Self Assessments, Integrated Functional Appraisal (IFA), Management of Environment, Safety and Health (MESH) reviews, etc.	• Annual LUR review cycle provides feedback. • Continuous feedback from the Non-Ionizing Radiation Safety Committee (NIRSC). • LBNL does not have systematic feedback on laser safety on campus; annual reviews of laser labs by the LSO have

		been suspended due to manpower issues.

H. Work Planning

LBNL – Work with Class IIIb and IV lasers requires a formal authorization as specified in Appendix B of Chapter 6 of PUB-3000. The formal authorization is through the AHD, which is completed by the work leader utilizing the AHD template as outlined in Appendix A of Chapter 16 of PUB-3000. After proposal by the work leader, the AHD is reviewed by the LSO and the Division Director (or designees) of the division in which the work will be performed and by EH&S. The Review Panel concluded that this is an adequate method of work planning. However, UCB does not receive the AHD and there is no form of systematic feedback on laser safety issues.

UC-Berkeley – Work with Class IIIb and IV lasers and certain Class IIIa lasers requires that the campus PI complete the LUR and submit it to the LSO. However, LBNL does not receive the LUR and there no form of systematic feedback on laser safety issues.

I. Hazard and Risk Analysis

LBNL – This is performed by the work leader in completing the AHD. The AHD outline in Chapter 16 of PUB-3000 requests information on both beam and non-beam hazards. Three AHDs were reviewed and found to be adequate with the exception of information on beam alignment procedures, which is discussed in more detail in later sections of this report.

Historic records of safety features audits were not available for review due to a problem with the computer system used by the previous LSO. Current safety features audits are integrated into annual AHD renewals and triennial IFA inspections.

UC-Berkeley – The analysis is through the LUR process which includes both beam and non-beam hazards. The PI is responsible for completing the LUR and submits it to the LSO who reviews it and submits it to the NIRSC for review. The LSO, not the PI, initiates annual re-review and re-issuance of the LUR.

Historic records of safety features audits are available as Laser Safety Survey Reports. A number of these reports were examined during the review. It was reported to the Panel that surveys had been performed annually, but that policy has been suspended due to manpower limitations.

J. ESTABLISHMENT OF CONTROLS

LBNL – The controls are based upon requirements in ANSI Z136.1 and are specified by the work leader in the AHD, per Appendix A of Section 16, PUB-3000. Three AHDs were reviewed and found to be sufficient in description of the control measures, although AHD 2060 describes entryway controls for a Class-4 laser controlled area where process controls have established a Class-1 work environment.

The laboratory has recently implemented a policy of either total beam enclosure or the use of eyewear within all laser laboratories (see Section V – Requested Comments).

Per requirements in ANSI Z136.1-2000, laser users are provided medical examinations. A review of the eye examinations shows that these exceed the requirements of Z136.1-2000.

UC-Berkeley – The total program is based on ANSI Z136.1. The LUR contains a section on required safety controls, which addresses select requirements from the ANSI standard, the FDA regulations, and UCB. A number of LURs were reviewed for Dr. Shen's and Dr. Fleming's laboratories. These appeared to have sufficient documentation of controls.

During the meeting, UCB EH&S representatives explained that UCB is considering a policy of total beam enclosure or eyewear, as implemented at LBNL. According to Panel member P. Lavely (e-mail dated June 11, 2003), the NIRSC has given priority to engineering controls and "has directed that the campus LSO to review each of the campus 3b and 4 lasers" and SOPs and provide guidance on any needed controls and revisions to the SOPs.

The campus requires that laser users receive eye examinations (Appendix D of the "Laser Safety Manual"). The examination criteria exceeds the recommendations in ANSI Z136.1-2000.

K. PERFORM WORK WITHIN CONTROLS

LBNL – The Panel performed an on-site review of two laser laboratories and two ALS beam line experiments. There were minor issues of nonconformance with the ANSI Z136.1 standard and questions about practices documented (or not documented) in the respective AHDs. [The specific findings are covered in Section III of this report.] However, in general the Panel found this item to be adequate.

According to the LBNL LSO, annual reviews (i.e., ANSI safety features audits) are performed and have been integrated into the annual AHD review. However, it was not possible to review documentation of previous annual reviews because of difficulty in accessing historic records maintained by the previous LSO.

UC-Berkeley – An on-site review was performed of two laboratories on campus, including the laboratory where the recent accident occurred. Minor items of non-conformance with the ANSI Z136.1 standard were identified. [The specific findings are in Section III, below.] The Panel concluded that the performance of work was in accordance with the specified controls.

Historically, the campus LSO performs an annual audit of laboratories where Class IIIb and IV lasers are used. These are documented in Laser Safety Survey Reports. The reports were reviewed for the two PIs responsible for the laboratories that were visited by the Panel, and found to be adequate. As mentioned above, the campus LSO no longer performs annual safety features audits because of staffing reductions. In light of these reductions, the frequency of campus laser inspections is being reevaluated.

L. Feedback and Continuous Improvement

LBNL – Per the requirements of section 16.8 of PUB-3000, all AHDs are reviewed annually by the operating division if no new hazards have been added. If there are new hazards, EH&S must review the AHD. Hence, feedback is provided by the LSO formally when the AHD is reviewed by EH&S.

The Laboratory has other means of providing feedback including self assessments, Integrated Functional Appraisal (IFA), MESH reviews, and lessons learned. Additionally, reviews, as provided by this Panel, are another form of feedback and improvement utilizing the expertise of a relatively diverse group of professionals.

UC-Berkeley – In general, LURs are reviewed by the LSO annually (Section II-D of the "Laser Safety Manual"). Modifications are initiated at the request of the PI. In special cases the NIRSC may modify the LUR, which would provide feedback to the PI.

The NIRSC establishes the campus laser safety policy and functions to resolve laser safety concerns. In so doing, the NIRSC provides feedback to both the LSO and laser users.

UCB does not provide LBNL systematic feedback on laser safety on campus. This does not apply to Donner and Calvin Laboratories where LBNL has laser safety responsibility and may perform scheduled inspections per the MOU. The MOU also requires reporting accidents to LBNL if LBNL personnel are involved. In the most recent accident in Dr. Shen's laboratory, UCB EH&S personnel informed LBNL of the accident promptly after the accident was reported to the LSO.

As noted above, the LSO has stopped performing annual inspections of laser laboratories. The reason reported to the Panel was insufficient manpower. Hence, this means of on-site observation with immediate feedback and documentation to the user is performed as time permits.

III. IMPLEMENTATION OF ANSI Z136.1-2000

A major charge to the Review Panel was to determine if the ANSI Z136.1-2000 standard is successfully implemented at both LBNL and for LBNL operations on the UCB campus. This standard was first adopted as an American National Standard in 1973 and has been revised and re-adopted five times. Currently, it is under active revision by the subcommittee responsible for the standard.

The standard is a consensus document developed by individuals who have a material interest in laser safety and includes representatives from a broad range of organizations including industry, academia, defense, military, government, health care, entertainment, and professional societies. The standard is termed a consensus standard because for its adoption it does not require unanimous approval, but must be approved by 75% of those voting. In general, it should be viewed as a guidance document that provides reasonable and adequate programmatic requirements.

Most of the programmatic requirements of this standard are contained in the sections on control measures, safety training, and medical examinations. The section on control measures is the most lengthy section of the standard. The fundamental tenet of this section is to control exposures so they are beneath the maximum permissible exposures (MPEs), the exposure limits. This may be achieved by the use of engineering controls or administrative and procedural controls. In Section 4.1 of the Standard, it states that "Engineering controls (items incorporated into the laser or laser system or designed into the installation by the user) shall be given primary consideration in instituting a control measure program for limiting access to laser radiation." The use of the word "shall" is so-called mandatory language in ANSI standards, so this paragraph requires that engineering controls be given the highest priority in specifying control measures.

However, most of the individuals on the Z136 committee are laser users or laser safety practitioners who recognize that it may not always be possible to implement engineering control measures and that, administrative and procedural control measures can also satisfy the basic tenet in many cases. Also, in Section 4.1 of the Standard, it further states that "If engineering controls are impractical or inadequate, administrative and procedural controls and personal protective equipment shall be used." Hence, the standard requires the user to first explore the use of engineering controls. However, if these will not work, then exposures must be controlled with administrative and procedural control measures.

Concerning the fundamental question about successful implementation of the standard at LBNL and UCB, as noted earlier, the general answer is "yes." Both programs are based upon the recommendations in Z136.1 and have implemented significant sections of the standard. However, some elements of the standard have not been implemented. In some cases, this appears to be by design. For example, LBNL has excluded the requirements to determine the nominal hazard zone (NHZ) in its laboratory space because, for Class-IV lasers, the extent of the NHZ will often be much greater than the dimensions of the laboratory. In other cases, items of nonconformance may represent inconsistent implementation of safety practices. As determined in the laboratory reviews, areas of nonconformance are also associated with individual laboratories. These items will be reviewed below.

Five laboratories were visited by the Review Panel members and panel observers. There were meaningful findings for four of these laboratories, and these are reviewed below. The comments below are derived from the observations of the author of this report and two panel observers, LSOs at Los Alamos and Lawrence Livermore National Laboratories. Findings may be of a positive or negative nature, or neutral (i.e., a statement of factual observation of the conditions of the laboratory at the time of the visit).

A. FINDINGS - LBNL

Specific and general findings are compiled in Table 3 and discussed below. Table 3 also includes a cross-reference to recommendations for program improvements. These recommendations are discussed in Section IV of the report.

Table 3 – Findings and Recommendations for LBNL

Location	Finding	Report No./Page	Recommendation	Report No./Page
General	AHDs provide little guidance on alignment	1/23	More attention should be paid to alignment procedures. Expand information in 16.6.1 of PUB-3000 on alignment	1/33 2/33
	Exception to Z136.1 on determination of Nominal Hazard Zones (NHZ)	2/23	Determine NHZ	8/34
	Eye exam requirements exceed Z136.1	3/23	None	
	Enclose or eyewear policy	4/23	Revise Chapter 16 of PUB-3000 to include significant policy statements	12/34
	Instructor-focused laser safety training	5/23	None	
2-333	Entryway controls adequate	1/23	Evaluate labs for controls that are inconsistent with degree of hazard	10/34
	Beams enclosed during operation; not known if enclosure material has been tested for application	2/23	Evaluate labs for controls that are inconsistent with degree of hazard	10/34
	Apparent Class 1 users' environment has some Class 4 entryway controls and "Danger" sign	3/23	Evaluate labs for controls that are inconsistent with degree of hazard	10/34
	"Notice" sign available for use during alignment, but no "Danger" sign for use inside lab	4/24	Use "Danger" sign inside and "Notice" sign outside of labs during beam alignment	5/33

	Eyewear improperly stored	5/24	Goggles should not be hung by headband. Eyewear should be stored where there is no hazard of overexposure	6/34 7/34
	Damaged eyewear stored with eyewear to be used	6/24	Discard damaged eyewear; if to be used for display, make sure to label as such and store separately	11/34
	No "panic button" in lab; labeling door push bar may be adequate	7/24	Evaluate Class-4 labs for conformance with ANSI requirement for "panic button"	9/34
	No laser alignment procedure available; alignment information in AHD minimal	8/24	More attention should be paid to alignment procedures. Expand information in 16.6.1 of PUB-3000 on alignment	1/33 2/33
Beam Lines 9.0.1 & 9.0.2	Beams enclosed during operations	1/25	None	
	Open beams during beam alignments	2/25	None	
	Two curtains around excimer bench; one is not a laser protective curtain and was torn	3/25	Ensure that documentation on non-standard control measures is available	4/33
	Burn spots on curtain, probably from tests performed by previous LSO; no documentation available for tests	4/25	Ensure that documentation on non-standard control measures is available	4/33
	Polycarbonate eyewear, not laser safety eyewear used during alignment of excimer laser; test data and documentation not available	5/25	Verification of level of optical density. Ensure that documentation on non-standard control measures is available	3/33 4/33
	Pulse energy turned down and eyewear used in alignment of 532-nm line from doubled Nd:YAG laser	6/25	Verification of level of optical density.	3/33
	Alignment performed at night and minor aisle demarcated	7/26	Use "Danger" sign inside and "Notice" sign outside of labs during beam alignment	5/33
	Little information available in AHD concerning alignment	8/26	More attention should be paid to alignment procedures. Expand information in 16.6.1 of PUB-3000 on alignment	1/33 2/33
	"Notice" sign should be used during beam alignment	9/26	Use "Danger" sign inside and "Notice" sign outside of labs during beam alignment	5/33

1. General Findings

1. As noted for specific laboratories, AHDs provide little information on alignment. Some members of the Review Panel and the laser users interviewed appear to be in opposition to providing more than general guidelines on alignment practices and documentation since the experiments are research in nature and optical components are frequently changed. In some laboratories, alignment occurs with sufficient frequency to be viewed as a regular procedure.

2. The LBNL laser safety program has adopted an exception to the determination of the nominal hazard zone primarily because the extent of the NHZ may be greater than the size of most laboratories. However, Chapter 16 of PUB-3000 states that "The term "Nominal Hazard Zone" (NHZ) is important in any discussion about laser safety." Chapter 16 also provides information on the determination of the NHZ and provides a compilation of NHZs for various laser parameters.

3. The LBNL requirements for medical surveillance (eye examinations) go well beyond the requirements contained in ANSI Z136.1.

4. LBNL has recently adopted a policy of "either enclose the beam or wear your eyewear." The basis for this approach is to require that there is always attenuation between the beam and the eye.

5. LBNL currently provides instructor-focused laser safety training using traditional classroom methods, but is planning on implementation of computer-based training.

6. Documentation of laboratory inspections are not available for review.

2. Laboratory: Ultrafast Photo, 2-333

1. Entryway controls include a lighted sign, ANSI-type sign, magnetically locked door, defeatable interlocks, and authorization.

2. Laser beam paths are enclosed during operation, providing, apparently, a Class 1 work environment. The enclosure is made from Gatorfoam® Graphics Arts Board. According to the manufacturer, this board is made with a core of polystyrene foam with facings made from wood-fiber-veneer-impregnated resin, materials that could possibly be ignited by an incident Class-IV laser beam. To account for this possible hazard, the researchers have painted the surface of this material with a flame retardant paint. However, it is not known if the material has been tested and demonstrated to be an effective laser barrier, and if this is documented.

3. According to the laser users, there is no access to the laser beam during normal operation, which means that this laboratory is a Class-1 laser environment. A lighted sign and an ANSI-type "Danger" sign were located outside the entryway to the lab. These

signs are commonly used where there is a Class 4 work environment (i.e., where there is an open beam path during operations), per sections 4.3.10.1(2) and 4.3.10.2.2 of ANSI Z136.1-2000. The ANSI standard requires the use of a "Danger" sign where there is a Class 4 Laser Controlled Area (i.e., an open-beam system during normal operation). Hence, a Class-4 warning sign is being used for a Class-1 laser application.

[Note: According to LBNL LSO T. de Castro, the current users have occupied this lab relatively recently and inherited the entryway control measures. Although this does not impact the unsuitability of the control measures as discussed above, it does explain their installation.]

4. An accessory, ANSI-type "Notice" sign was located within the lab and is placed outside the entryway when beam alignments are being performed. No accessory, ANSI-type "Danger" sign was observed within the laboratory.

5. Laser safety eyewear, goggles, were hanging by the elastomeric bands just within the entryway. The method of storage is poor as it allows dust to collect within the facepiece and stresses the band and facepiece due to hanging. Also, there is a question of location of the eyewear. If the laboratory is only a Class-4 environment during beam alignment when the "Notice" sign is placed on the door, then authorized personnel must have access to the eyewear before entering the laboratory, so the eyewear should be stored outside of the lab, in the present configuration.

6. One pair of eyewear had been damaged by exposure to laser radiation. Although the users were aware of this, this pair of goggles was hanging by the entryway where it could be used during alignment.

7. No EPO/EMO switch ("panic button") was available within the lab. It was noted during the review, that the push-bar on the exit door may function as a panic button, but was not labeled as such. Also, according to AHD 2060, "The main shut-off power will be located on each laser power supply and will be sign-posted for shutdown in case of an emergency." However, these are individual switches for multiple power supplies located around the room, and do not satisfy the requirement for a panic button in the ANSI Z136.1 standard.

[During the review, LBNL staff noted that one section of the ANSI Standard, 3.4.1 of the 1993 standard, was categorically excluded from their program and this was believed to be the section on the EPO/EMO switch. Upon checking, it was determined to be the section on the nominal hazard zone (NHZ). As discussed below, determination of the NHZ is part of the hazard evaluation. The NHZ is the region of space within which the levels of laser radiation exceed the MPE (i.e., the region where an overexposure may occur). This issue is discussed in more detail below.]

8. No laser alignment procedure was available upon request. However, alignment is addressed in AHD 2060. The guidance that is given appears is general but does provide the framework for safety, as many standard recommendations for safe alignment

practices are included (e.g., low power, authorized personnel, and protective eyewear). However, the absence of detail on methods make it difficult to evaluate the utility of this section of the AHD. This includes methods of diffuse viewing with appropriate eyewear and the mechanics of troubleshooting.

For example, the values of optical density mentioned in AHD 2060 are quite high, between 7 and 20. Such eyewear will not allow the user to view "the lowest possible laser output" as claimed in the AHD, unless the energy is converted to another wavelength with a viewing aid. Also, the potential for multiple wavelengths during alignment and the suitability of eyewear may be an issue in this lab since both visible and near-infrared wavelengths are in use. This is not discussed in the AHD, and the method of troubleshooting to determine the misaligned optic is not mentioned.

3. Laboratory: ALS - Beam Lines 9.0.2 and 9.0.3

1. The laser beams are enclosed during normal operation.

2. Open beams are accessible during beam alignments of both the excimer and the frequency-doubled YAG lasers.

3. Two curtains were located around the bench for the excimer laser. One was a laser protective curtain with a sign pocket, while the other was not a laser protective curtain. The latter curtain had a significant tear at one location—on the main aisle—where a cabinet had been placed. However, although the curtain is significantly damaged, the potential for overexposure is low and would take multiple reflections for this to occur.

4. According to LSO T. de Castro, there were also burn spots in the curtain that appear to be caused by a laser beam. Most likely this occurred when the curtain underwent local tests under the guidance of the previous LSO to determine if it could be a suitable curtain in a specific application. No documentation is available to demonstrate the results of such a study.

5. For the excimer laser radiation, polycarbonate safety eyewear was available for use. This eyewear was not labeled for optical density and wavelength for which protection is afforded as required in ANSI Z136.1-2000, Section 4.6.2.7. According to T. de Castro, the eyewear had been evaluated by the prior LSO, but documentation is unavailable.

6. According to one of the users, during alignment of the frequency-doubled YAG laser, the power is turned down to low levels and laser protective eyewear is worn. The eyewear has an optical density of 7 which would attenuate the incident light by a factor of 10 million times. A low-power beam would not be visible with such high levels of optical density. Based upon these facts, this issue was explored in greater detail. According to the user, the beam energy is turned down to around 10 millijoules (mJ) per pulse and passed through a mesh that further reduces it to 0.1 mJ per pulse. This equals an average power of 10 milliwatts (low end of Class 3b).

7. Due to the open nature of the workplace, certain alignment steps are performed at night when there are few people in the area. The minor aisle leading past the lasers is demarcated to limit access.

8. There were no written alignment or troubleshooting procedures available. AHD BE1012 does mention alignment, but provides little detail. However, it was noted that due to the accessibility of the minor aisle that leads past the beam paths, alignments are performed at night when few personnel are in the building; the aisle is demarcated; and some type of signage is used. Although there are just two users who would perform this task, alignment tasks produce an increased risk to the users and possible passers-by, for this experimental setup.

9. When performing alignment, the users effectively establish a temporary laser controlled area, although a "Notice" sign is not available or used.

B. Findings – UC-Berkeley

Specific and general findings for UCB are compiled in Table 4 and discussed below. Table 4 includes a cross-reference to recommendations for program improvements which are discussed in Section IV of the report.

Table 4 – Findings and Recommendations for UC-Berkeley

Location	Finding	Report No./Page	Recommendation	Report No./Page
General	The topic of stray beams is not addressed sufficiently in the Laser Safety Manual and Training Supplement	1/28	Eliminate or label upwardly-directed beams	3/35
	There are many repeat items on annual audit reports and some of these action items took longer than expected to resolve	2/28	Identify significant action items and track to resolution	5/35
	Audits are no longer performed annually due to manpower restrictions	3/29	Eliminate backlog of inspections and continue audits	4/35
	There is no mention of eyewear inspection in annual audits reports and the inspection form does not include a field on eyewear	4/29	Periodic inspections of eyewear should be made and the inspection form modified with the appropriate field; Ensure that users receive training on protective eyewear	9/36 10/36
	Laser safety training is "read and sign"	5/29	None	
	The Responsibility for EH&S Document hardly mentions lasers and the NIRSC is misnamed within	6/29	Revise Document as recommended	12/36 13/36 17/37 18/37

				19/37
	Eye exam requirements exceed Z136.1	7/29	None	
	Standardized emergency procedure is posted in labs	8/29	None	
	There is insufficient information on alignment in the LUR, procedures, and training documents.	9/29	Revise pertinent documents per recommendation and require more specific information from users	6/35
Hildebr. B71	Lasers within restricted area	1/30	None	
	Labs are Class-4 laser controlled areas	2/30	Ensure that suitable entryway controls are in place	15/36
	Some entryway control features are absent, so it does not conform with requirements in ANSI standard	3/30	Ensure that suitable entryway controls are in place	15/36
	There is an open question about the lighted "Danger" sign outside the lab: is it in an interlocked circuit or not?	4/30	Ensure that suitable entryway controls are in place	15/36
	"Notice" sign is not used during service (alignment)	5/30	ANSI-type "Notice" signs should be during beam alignment	14/36
	"Panic buttons" located in labs	6/30	None	
	Many laser users have received laser safety training provided by both UCB and LBNL	7/30	None	
	Beam height is located beneath eye level for a standing person; users state that beam path is controlled to minimize stray beams	8/30	Ensure that the beam is not delivered at eye level	11/36
	Beam blocks located at locations around bench where there are reflections from optics	9/31	Ensure that the beam is not delivered at eye level	11/36
	Labs are interconnected but there are no entryway controls to warn persons who may enter an adjacent lab	10/31	Ensure that suitable entryway controls are in place	15/36
	Eyewear was stored on a shelf or desk next to the optical bench	11/31	Eyewear should be stored where there is no hazard of overexposure	8/35
	Optical tables are a seismic hazard.	12/31	Ensure optical benches are secured	21/37
	Open beam power reduced by losses on bench top from Class 4 levels to Class 3a levels or less	13/31	None	
Birge 145	Single red light bulb above entryway door indicates laser is operating	1/31	Ensure that suitable entryway controls are in place	15/36
	Red light activated manually with a light switch inside lab; circuit is interlocked to lasers which will not operate without light switched on	2/31	None	
	Entryway control measures not implemented to be consistent with ANSI Z136.1	4/31	Ensure that suitable entryway controls are in place	15/36
	Eyewear located inside room requiring users to enter potentially hazardous area before putting it on	5/31	Eyewear should be stored where there is no hazard of overexposure	8/36
	The laser eyewear does not cover	6/32	Verify wavelength compatibility and	7/36

	all wavelengths, specifically 532 nm is not covered		level of optical density is appropriate	
	Nd:YAG laser is operated with interlock switch permanently bypassed; LSO is aware and has approved operation	7/32	None	
	Enclosure of beam paths is not followed uniformly in all Dr. Shen's labs	8/32	Eliminate, enclose or label upwardly directed beams	3/35
	No standard operating procedure and little information on alignment; this has since been remedied	9/32	Revise pertinent documents per recommendation and require more specific information from users	6/35
	Users are not familiar with equipment listed on the checklist for the laser in this room	10/32	Unique procedures or requirements should be included with LUR and in employee training	17/37
	Locations of upwardly directed beams are not labeled	11/32	Eliminate, enclose or label upwardly-beams	3/35
	The laboratory laser safety person has received no special training	12/32	Laboratory laser safety personnel should receive training commensurate with level of hazard, duties and expectations	15/36

1. General Findings

1. The eye injury in Dr. Shen's laboratory occurred when there was a reflection (stray beam) from an optic that had been located in the beam path by a previous [unidentified] user. A review of Laser Safety Survey Reports for Dr. Shen's laboratories in Birge Hall shows that stray beams were a topic mentioned in 8 of 9 reports (see reports dated 4/5/95, 4/9/96, 4/2/97, 7/15/97, 3/25/98, 3/30/99, 1/18/00, 11/16/00). A check of survey reports for laboratories under the direction of other PIs in the time frame of the reports above found the same or similar comments about stray beams, so this appears to be a standard recommendation in the reports. However, the topic of stray beams is not addressed in the section on alignment in the "Laser Safety Training Supplement" of the UCB "Laser Safety Manual."

[Note: "Stray laser radiation" is mentioned under the heading of "enclosures, beam barriers, beam stops, and collimators" for normal operation, and stray beams are implied under the heading of "preventing and controlling reflections."]

2. A review was conducted of Laser Safety Survey Reports for Dr. Fleming's and Dr. Shen's laboratories. It was noted that there were many repeat items documented on reports from one year to the next. According to LSO E. Ciprazo, these action items took longer than expected to resolve due to the requirement for multiple reviews and approvals, and none of these items represented imminent hazards to laser users. However, when it takes a year to approve and install the appropriate lighted warning signs and to prepare procedures addressing alignment, it raises questions about the proper

focus of management on implementation of significant aspects of the laser safety program.

3. It appears that prior to about April 2002, inspections of lasers were being performed annually. However, due to current manpower restrictions, the LSO has been unable to perform annual audits of laser labs. A review of select reports for Dr. Fleming and Dr. Shen's laboratories demonstrates that these audits are useful in identifying items of concern dealing with control measures and administrative topics such as training and medical examinations. ANSI Z136.1-2000 requires periodic audits of safety features of the laser installation and laser equipment (Section 1.3.2.8).

4. The ANSI standard also requires that a periodic safety inspection of laser protective eyewear be performed, with a recommendation of an annual inspection (Section 4.6.2.8). Although protective eyewear is discussed in a number of Laser Safety Survey Reports, there is no mention of an inspection in reviews of Dr. Fleming's lab, but eyewear "status" is addressed for Dr. Shen's lab in a report dated 4/5/95. Also, the Laser Inspection Form does not include a field for eyewear inspection, and inspection of eyewear is not mentioned in the "Laser Safety Manual" nor in the "Laser Safety Training Supplement."

5. Laser safety training at UCB requires users to read the "Laser Safety Manual," training supplement, and LUR, then take a quiz and send the quiz and signed training certificate to the LSO.

6. A review of the Responsibility for Environment, Health and Safety Document shows that the document is weighted to environmental issues, biological and chemical hazards, and laboratory safety. Radiation safety and laser safety, specifically, are not included in the "particular responsibilities" assigned to managers, although responsibilities are discussed in the "Laser Safety Manual." Laser safety is only identified in this document under the heading of oversight committees, where the "Laser Safety Committee" is noted. However, according to presentations by UCB EH&S managers and the LSO, this is a misnomer, as the "Laser Safety Committee" is currently named the "Non-ionizing Radiation Safety Committee" or NIRSC.

7. The UCB requirements for medical surveillance (eye examinations) go well beyond the requirements contained in ANSI Z136.1-2000.

8. A standardized laser "emergency procedure" was observed in the laboratories reviewed by the Panel.

9. There is little information on alignment in the LUR, operating procedures, and training documents.

2. Laboratory: Hildebrand B71 – Dr. Fleming's Lab

1. The laser labs are within a restricted area, so access is limited to authorized individuals and their guests.

[Note: In a historical report, Laser Safety Survey Report dated 2/23/99, the previous LSO found "the doorway to the laboratory complex propped open with a rubber door stop. No one was in direct attendance of the area although Ms. Kaufman was working at her computer well inside the complex," and was unaware that the door to the laboratory suite was propped open. In part, the report notes that "the use of the outer locked door was a requirement in order to allow your staff uninterrupted access to the laser suites." UCB LSO E. Ciprazo reports that he has not observed a reoccurrence of this finding.]

2. The beam path is complex and, for the most part, fully open. Hence, these labs are Class 4 Laser Controlled Areas, per ANSI Z136.1, and the provisions of the standard on entryway controls applies. Section 4.3.10.2.2 requires that there is to be a "panic button" (EMO/EPO) and implementation of one of three entryway controls: non-defeatable, defeatable, or procedural controls.

3. Installed entryway controls include authorization and lighted signs. The entryway doors are not interlocked and there is no light-blocking barrier inside the door. Hence, the lab does not conform to the entryway controls as specified in the ANSI standard.

4. Lighted signs are located above the entryways to the labs. It is not known if the lamps in the signs are interlocked with the laser systems or not. When questioned, two of the laser users (graduate students) stated that they are on the lookout for burned out lamps and replace them when observed. However, according to the campus LSO, these fixtures are supposed to be wired into an interlock circuit on the laser system. The concern is that it is possible for the lamp to burn out while the laser remains operational, if not interlocked with the laser system.

5. When the laser system is serviced (e.g., alignment), a hand written paper sign is taped on the exterior of the entryway door, and the lighted "Danger" sign stays on. ANSI Z136.1-2000, Section 4.3.12. requires the use of a "Notice" sign.

6. The labs do have EMO/EPO switches located adjacent to the entryway door. These are configured to terminate power within the laboratory when activated. The switches are a red, mushroom type contained within a wire guard to prevent accidental activation.

7. Although the minimum requirement for training is completion of the campus "read and sign" module, the laser users have received laser safety training provided by both the campus and LBNL.

8. The beam height is located below eye level for a standing individual, but appears to be at the height for a seated person. According to the users, the optics and optomechanical

elements are set up so that if there is an errant beam, it will be maintained in the plane of the optics on the optical bench (i.e., it will not be elevated).

9. Beam blocks are maintained at certain locations around the optical bench. According to lab laser safety person, D. Parkinson, beam blocks are located where they find reflections from the face of optics such as lenses, crystals, or prisms, as well as in the direction of any desk or computer.

10. The labs are internally interconnected. The door leading into/from each lab has no indication of the operation of the laser in the adjacent lab. Hence it is possible for a worker from one lab to enter into a potentially hazardous condition in the adjacent lab without encountering access controls.

11. Eyewear is only worn in this lab when the laser system is serviced (e.g., during beam alignment). Eyewear was not stored outside of entryway doors or interior doors accessing adjacent labs. According to LSO E. Ciprazo, eyewear is usually stored in a central location in each room in a hanging pouch. In a recent visit, the eyewear was stored on a shelf or on a desk next to the optical bench.

12. Optical tables are unsecured and are a seismic hazard.

13. According to the users, Class 4 levels of laser radiation are emitted from the laser, but losses through the optical path reduce the power on the bench to Class 3a levels or less.

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3. Laboratory: Birge 145 – Dr. Shen's Lab

1. Each lab in this area has a single red light bulb located above the exterior of the entryway door indicating that the laser is on.

2. The red light is activated manually by a switch located within the lab. This circuit is interlocked to the laser(s) within the room, so if it is not switched on, there is no access to the beam.

3. The red light is the primary indication that the laser is operating, regardless whether it is being used for normal operation or being serviced (e.g., beam alignment). No ANSI-type "Notice" sign was available to indicate service conditions.

4. The entryway door is not interlocked and administrative or procedural controls were not implemented (see ANSI Z136.1-2000, Section 4.3.10.2.2).

5. Eyewear was located inside the room, adjacent to the entryway door. This requires the users to enter into a potentially hazardous area before donning the eyewear (e.g., during beam alignment).

6. Four pair of eyewear are available for use in this laboratory. The combined spectral coverage of the eyewear is 190-420 nm, 710-1080 nm, and 5000-11,000 nm. However, according to LUR No. 1134, the Nd:YAG laser may be operated at the second harmonic, 532 nm, a wavelength that is not covered by any of the available eyewear.

7. The Nd:YAG laser protective housing interlock switch has been permanently bypassed. One of the laser users (graduate students) stated that this was because the laser overheats during normal operation, so the users operate the laser with the protective housing raised to allow cooling, and raising the protective housing requires the interlock to be bypassed. The UCB LSO was aware of this and stated that when he determined that the users were doing this, he found that they were operating the laser with the protective housing completely removed from the laser head. ANSI Z136.1-2000 does allow the operation of a laser without the protective housing (Section 4.3.1.1); however, the ANSI standard requires that the LSO perform a hazard analysis and ensure that the appropriate level of control measures is instituted. The UCB LSO had completed this analysis.

8. The laser beam path was enclosed for operation after the accidental exposure that occurred in March of 2003. Although other labs with similar laser hazards within this area under the control of the same PI were not inspected, according to UCB EH&S personnel, beam paths in these labs are not totally enclosed, so the enclosure approach is not followed uniformly. Although ANSI Z136.1-2000 does not require that all beams paths be enclosed, it strongly encourages it. [Section 4.1: "Enclosure of the laser equipment or beam path is the preferred method of control, since the enclosure will isolate or minimize the hazard."]

9. There was no standard operating procedure, but there is some information on alignment. [Note: Since the Panel met, an SOP for operation and alignment has been developed, reviewed by the PI and LSO, approved, and placed into use.]

10. A one-page checklist is available for the laser system in this room. When two of the users were asked about the location of the Pellin Broca prism that is noted on the checklist, they were unaware of its location within the system.

11. Beam terminations are utilized by upwardly directing the beam into beam dumps. Although not all of the dumps were installed in the lab due to the recent installation of the enclosure panels, there was no signage or labeling to indication where these locations were. Laser users in this laboratory should be acutely aware of the increased risk of exposure due to upwardly directed beams, because the recent accident that occurred in this lab was from a reflection from an optic located at a beam dump

12. According to the laboratory laser safety person, he has received no laser safety training beyond that given to all laser users.

IV. RECOMMENDATIONS

A. LBNL PROGRAM

1. Pay more attention to documenting alignment procedures, as part of the AHD. This includes work planning, hazard analysis, establishment of suitable controls, and the actual performance of alignment tasks unique to a specific system as documented.

As noted earlier, there is some general opposition among researchers to documenting alignment or troubleshooting practices and procedures on the basis that there are too many variables in alignment and troubleshooting, and alignment is a routine practice in some laboratories. However, it is just that reason, the multiplicity of variables, that makes it paramount that significant or unique aspects of alignment or troubleshooting be given ample forethought and planning, and documented accordingly. This seems to be especially important in a dynamic work environment that includes visiting scientists and students.

It has already been stated in the recommendations for the UC-Berkeley program and it is a well-known fact in laser safety: approximately one-third of <u>all</u> serious eye injuries from laser beams occur during alignment. Where the information is available, the majority of these injuries occur to scientists and technicians in laboratories. [Note: Chapter 16 of PUB-3000 states that "The likelihood of a laser accident is greatest during alignment process: 60% of laser accidents in <u>research settings</u> can be traced to alignment."]

There is some general guidance on alignment provided in Chapter 16 of PUB-3000, but this is brief and includes other programmatic requirements (e.g., medical approval, etc.) as well. Two guidance documents on beam alignment principles have been included in Appendix A of this report.

2. The information contained in Section 16.6.1 of PUB-3000 on "Laser Alignment Guidelines to Help Prevent Accidents" should be expanded. As noted above, some general information on alignment is included in the appendix of this report.

3. The level of optical density provided by laser protective eyewear should be verified as being appropriate for alignment. This is fundamental to the successful establishment of laser protective eyewear as a control measure.

4. Documentation for non-standard safety control measures should be available with specific attention to polycarbonate safety eyewear for UV and infrared-C wavelengths and polymeric (welding) curtains. Copies of this documentation should be maintained as part of the hazard evaluation.

5. An ANSI-type "Danger" sign must be located within the space when service activities—such as those denoted by the use of the "Notice" sign—are in progress (see

Section 4.7.3.3 of Z136.1-2000). This applies to laboratories where it is necessary to establish a temporary laser controlled area during beam alignment.

6. Laser safety goggles should not be stored by hanging with the elastomeric headband.

7. Laser safety eyewear should be stored in a location where no hazard exists for individuals donning the eyewear, such as storing protective eyewear within a laser controlled area.

8. The nominal hazard zone (NHZ) should be determined for all Class IV lasers or Class 4 user environments, as a part of the overall hazard analysis. It is true that the extent of the NHZ for the direct beam of a Class IV laser is much greater than the dimension of most laboratories and its determination, therefore, may be viewed as unnecessary. However, the use of optics often reduces the extent of the NHZ, in which case it may be smaller than the dimensions of the room and may, in fact, not extend beyond the optical bench. Also, besides defining the extent of the hazard, the NHZ is an instructional tool that may be especially useful to students or individuals who are new to work with lasers.

9. Class 4 laser laboratories should be evaluated for conformance with the requirements from the ANSI standard (Section 4.3.10.2.1) for a "panic button" and implement corrective actions as necessary.

10. Laser laboratories may have control measures that exceed the requirements in ANSI Z136.1-2000. Specifically, the Ultrafast Photoelectric Spectroscopy Lab 2-333 lab meets the definition of a Class 1 laser use environment, but has entryway control measures required for a Class 4 laser controlled area. In such cases, the potential hazard is vastly overstated. Laboratories with similar set ups should be evaluated to determine if the appropriate level of control is implemented.

11. If damaged eyewear, such as that found in Lab 2-333, is to be kept for instructional purposes, it should be stored separately from in-use eyewear and clearly marked as "out of service." If the damaged eyewear found in this lab was still in use, note that Section 4.6.2.8 of the ANSI standard requires that eyewear be inspected for pitting, cracking and "Eyewear in suspicious condition should be tested for acceptability or discarded."

12. Chapter 16 of PUB-3000 should be reviewed and revised to include important policies such as enclosure of the total beam path or the use of eyewear, and the exclusion of the requirement to determine the NHZ.

13. The records of the previous LSO are a significant resource and should be available. As noted, they are not currently available due to computer system difficulties. Verbal reports indicate that important elements of the hazard evaluation of at least one of the laser applications reviewed by the Panel (ALS Beam Lines 9.0.1 and 9.0.2) should be in these records, as well as documentation of annual safety features audits.

B. UC-Berkeley Program

1. Although the authority for work in Appendix I spaces rests with UCB, LBNL cannot delegate responsibility for the safety of its employees. Accordingly, UCB and LBNL must work together to assure that the level of laser safety protection afforded by both programs is equally effective.

2. The question of who is "line management" at UCB is broader than the area of laser safety. This review has demonstrated that recognition of responsible management is an integral part of safety and the functional implementation of a safety program. The Responsibility for Environment, Health and Safety Document does define managers as noted above, and this definition places responsibility at the PI level; however, it is clear that not all PIs consider themselves to be line management for safety. Campus PIs should be made aware that they are responsible for safety in their laboratories, and this responsibility cannot be delegated.

3. Upwardly-directed beams should be eliminated or enclosed as practical. When necessary, they should be labeled at all locations.

4. The backlog of inspections of Class IIIb and IV lasers should be eliminated and the safety features audit should continue on an annual basis. Panel review of inspection reports for laboratories under the direction of Drs. Shen and Fleming and others demonstrates that the annual inspection is a valuable tool and has identified areas requiring improvement (i.e., action items) at each annual visit.

5. A system should be implemented to identify significant action items determined during the annual audits (or at other times) and track these to resolution. Such a system should be beyond the scope of the annual inspection (i.e., it should not depend upon waiting for the next annual audit as the vehicle to demonstrate and document resolution.)

6. More attention should be given to alignment practices in the LUR, operating procedures, and training documents. The "Laser Safety Manual" includes two full pages on laser pointer safety guidelines, but just three paragraphs on beam alignment. Laser pointers have been responsible for apparent threshold retinal effects in few documented cases, and in three of these the individuals purposely overcame their aversion response to bright light and stared into the beam for many seconds. On the other hand, laser users were performing beam alignment during approximately one-third of serious eye injuries, according to one accident/incident data base. Some specific recommendations are:

> a. A section on "Alignment Guidelines" should be included in Appendix B of the Supplement. (There are two statements on alignment principles that may be used in development of these guidelines, included in Appendix A of this report.)

b. The topic of stray beams should be addressed more overtly in appropriate sections of the Manual and Supplement.
c. More detailed alignment SOPs should be required.
d. An alignment practices section should be included in the Laser Inspection Form.
e. Comments on alignment practices should be included in all Laser Safety Survey Reports.

7. The wavelength compatibility and level of optical density provided by laser protective eyewear should be verified as being appropriate for alignment. This is fundamental to the successful establishment of laser protective eyewear as a control measure.

8. Laser safety eyewear should be stored in a location where no hazard exists for individuals donning the eyewear, such as locating protective eyewear within a laser controlled area.

9. A periodic safety inspection of laser protective eyewear should be performed as required by ANSI Z136.1-2000.

10. With the reliance on eyewear as a fundamental protective device during beam alignments, it should be addressed in training and included as a documented aspect in all laser safety surveys.

11. Ensure that the laser beam is not delivered at eye level for a standing or seated person.

12. The UCB Responsibility for Environment, Health and Safety Document should be distributed to all responsible parties named in the document, especially those who are or could be viewed as line managers. The sections for administrators/managers and individuals should be included in the appendix of the "Laser Safety Manual" and at least one question concerning the Responsibility for Environment, Health and Safety Document should be included in the quiz.

13. The UCB Responsibility for Environment, Health and Safety Document should be revised to include specific mention of laser safety (and radiation safety) in the category of topics of "particular responsibility" of managers, within the "Responsibilities of Department Administrators and Managers" web page.

14. ANSI-type "Notice" signs should be used during service of laser systems. This applies to alignment of lasers in laboratories with lighted "Danger" signs that are illuminated at all times the laser is operational.

15. Ensure that suitable entryway controls are implemented at primary entrances and where adjacent laser laboratories are internally interconnected.

16. Laboratory laser safety personnel should receive training commensurate with the degree of hazard of the lasers in their labs, as well as parallel with their duties and expectations.

17. Unique procedures or requirements (e.g., the checklist in Dr. Shen's lab) should be included with the LUR. Users should be questioned at the time of the annual audit to ensure that they are familiar with the procedures/requirements and their application.

18. The UCB Responsibility for Environment, Health and Safety Document should be revised to change the name of the Laser Safety Committee to the Non-ionizing Radiation Safety Committee.

19. The UCB Responsibility for Environment, Health and Safety Document should be revised to include a contact list naming the Chair and Support in the oversight committee web page. Currently, the Laser Safety Committee web page includes only a link to the contact information for the radiation protection staff, with no mention of involved faculty. Other oversight committees include committee contacts, so this minor change will bring consistency with the other committee pages and draw focus to the appropriate faculty contact(s).

20. The "Laser Safety Manual" should be revised to state that it does not include all Class IIIa lasers as is currently stated.

21. All optical benches should be secured so that they do not pose a hazard to individuals in an earthquake.

22. Quiz question 18 should be checked. It appears to have the incorrect wavelength for the maximum spectral responsivity of the human eye.

V. REQUESTED COMMENTS

During the Panel meeting, two requests were made for the chairman to include comments on specific topics in this report. These topics are 1) the new policy at LBNL to enclose the beam or wear eyewear, and 2) the use of computer-based training. These are reviewed below.

A. LBNL Beam Enclosure or Eyewear Policy

Laser radiation has been demonstrated to produce threshold-dependent effects to the eyes and skin. As with numerous potentially hazardous agents, the threshold concept means that there is a safe dose of the agent, in this case laser radiation. This is the basis for the occupational exposure limits, ANSI Z136.1 maximum permissible exposures or MPEs, which are safe levels of exposure. A primary job of the LSO is to determine or effect the determination of where there are potential exposures to levels of laser radiation in excess of the MPEs (i.e., overexposures). Control measures are required where these zones of potential overexposure exist. Succinctly put, the method the LSO follows is to 1) determine the MPE, 2) understand the potential avenues of exposure (e.g., direct beam, specular reflections, diffuse reflections) developed from first-hand knowledge of the application, 3) model the potential for overexposure in these areas, and 4) specify the appropriate level of engineering and/or administrative controls.

One interpretation of the eyewear/total enclosure policy is that the LBNL laser program has excepted itself from performing a complete hazard analysis by not determining the NHZ for its specific laser applications. To say that the extent of the NHZ is greater than the size of the rooms in which they are used is simplistic, at best, and ignores the fact that during the operational phase of laser use beams follow a predetermined path, and knowledge of possible paths is a highly significant issue. Also, as noted earlier, the use of optics may have the effect of reducing the extent of the NHZ.

This does not mean that accidental overexposures do not occur during normal operations. However, to our knowledge, such accidental exposures most often occur in industrial—not laboratory--applications and are associated with user error or computer malfunctions. Laboratory accidents with lasers occur most often during beam alignment or other service-type applications, and appear to be due to direct human interactions with the beam.

It is a recognized good practice that as much of the beam path as practical should be enclosed during normal operation. It is also a recognized good practice that the open beam path should be thoroughly analyzed, as well as possible fault conditions, to understand the potential for overexposure in a given application. Obviously, total enclosure of the beam path precludes the use of laser protective eyewear, because a Class 1 user environment has been established by enclosure. However, in practice, a thorough analysis of the beam path and potential beam paths for normal operations can identify areas outside the NHZ where the use of eyewear is not required.

As with all safety issues, focus should be brought to bear on the known, dominant cause of accidents, specifically accidental overexposure to laser radiation in laboratories, which is beam alignment. When performing alignments with open beams, the presumption that the laser beam could overexpose individuals at all points within the laboratory is acceptable, and suitable control measures, including laser protective eyewear, must be required.

With this said, it is obvious that the strengths of the new LBNL policy are that it focuses on beam enclosure. Additionally, it is easy to enforce. Conversely, the main limitation of such a policy is that it gives equal weight (or priority) to protective eyewear and beam enclosure.

Thus, if beam paths are not totally enclosed, it requires the use of laser protective eyewear, even when a hazard may not exist, and this may have the unwanted effect of diluting the program one is attempting to strengthen.

B. Laser Safety Training Programs

LBNL - As noted in the findings, plans are in place to change the method of laser safety training from classroom to computer-based instruction. In general, the various instructional methods have been characterized by the retention of information by participants as a function of day after the learning experience. Seven days post-learning, individuals who read material had 10% retention versus 50% retention for individuals who both saw and heard information. The highest retention, 90%, occurred when the learners were saying and doing, or participating in the learning experience. The say/do methods of training are little utilized in health and safety training, but are highly regarded and utilized in industry where new employees are trained to do specific tasks in the manufacturing environment.

So, a general conclusion is that unless the CBT program involves the learner in more than reading material on the screen, the retention of information will be minimal and training will not be optimal. The best method involves hands-on instructional methods where the learners actively participate in the session and are involved in teaching one another.

UC-Berkeley - As noted earlier, the primary method of laser safety training involves individuals reading assigned material, taking a quiz, and submitting appropriate documentation to the LSO. The LSO does provide individual and group training in some cases.

In general, the various instructional methods have been characterized by the retention of information by participants as a function of day after the learning experience. Seven days post-learning, individuals who read material had 10% retention versus 50% retention for individuals who both saw and heard information. The highest retention, 90%, occurred when the learners were saying and doing, or participating in the learning experience. The say/do methods of training are little utilized in health and safety training, but are highly regarded and utilized in industry where new employees are trained to do specific tasks in the manufacturing environment.

A general conclusion is that the primary method is less than optimum with regard to the retention of information by the learners. The best method involves hands-on instructional methods where the learners actively participate in the session and are involved in teaching one another. This reviewer has no knowledge of the specific methods utilized in the LSO small-group training. Nevertheless, it is likely that the retention of knowledge is much higher in individuals who participate in this training since individuals probably see and hear information, and may actively participate.

APPENDIX A - ALIGNMENT GUIDELINES

Laser Alignment Procedure
David Taylor, CLSO,
LSO Lawrence Livermore National Laboratory

(Note: the RI/DLSOs are free to edit verbiage and choose which points to include and tailor to their setup in the "*Procedural Considerations*" and the "*Alignment Methods to be used for this laser*" sections only. Leave the intro line and paragraph below. It is intended that this wording below be either 1) included into the body of an OSP, 2) as an appendix, 3) attached to the IWS, 4) or as a stand-alone document. In all cases, it must be reviewed by the Responsible Individual (and possibly signed off by the LSO/DLSO) periodically, at a minimum annually or as operations change). **Delete this paragraph before you finalize the procedure. Don't forget to edit the header above.**

The techniques for laser alignment listed below will be used to help prevent accidents during alignment of this/these laser system(s).

The requirements for alignment procedures for class 2 and above lasers and laser systems, found in the EH&S chapter "Lasers" and ANSI Z136.1, do not apply to laser pointers, surveying equipment, barcode readers, hand held laser diagnostic equipment or similar general industry equipment.

Procedural Considerations

1. To reduce accidental reflections, watches, rings, dangling badges, necklaces, reflective jewelry are taken off before any alignment activities begin. Use of non-reflective tools should be considered.
2. Access to the room/area is limited to authorized personnel only.
3. Consider having someone present to help with the alignment.
4. All equipment and materials needed are present prior to beginning the alignment
5. All unnecessary equipment, tools, combustible material (if fire is a possibility) have been removed to minimize the possibility of stray reflections and non-beam accidents.
6. Persons conducting the alignment have been authorized by the RI
7. A NOTICE sign is posted at entrances when temporary laser control areas are setup or unusual conditions warrant additional hazard information be available to personnel wishing to enter the area.

Alignment Methods to be used for this laser

1. There shall be no intentional intrabeam viewing with the eye. (This statement must remain. Do not delete.)

2. Co-axial low power lasers should be used when practical for alignment of the primary beam.
3. Reduce the beam power through the use of ND filters, beam splitters and dumps, or reducing power at the power supply. Avoid the use of high-power settings during alignment as much as is practical.
4. Laser Protective Eyewear shall be worn at all times during the alignment, within the parameters and notes established on the accompanying laser table.
5. (this paragraph must be accepted or deleted in it's entirety) The LSO has authorized reduced optical density eyewear to allow the beam spot to be seen. Measures shall be taken and documented to ensure that no stray hazardous specular reflections are present before the lower OD eyewear is worn. A return to the Maximum OD eyewear as listed in the laser table will be made when the alignment is complete. The eyewear is labeled as alignment eyewear and is stored in a different location than the standard laser eyewear for this operation.
6. Skin protection should be worn on the face, hands and arms when aligning at UV wavelengths.
7. Beam Control- the beam is enclosed as much as practical, the shutter is closed as much as practical during course adjustments, optics/optics mounts are secured to the table as much as practical, beam stops are secured to the table or optics mounts.
8. Areas where the beam leaves the horizontal plane shall be labeled.
9. Any stray or unused beams are terminated.
10. Invisible beams are viewed with IR/UV cards, business cards or card stock, craft paper, viewers, 3x5 cards, thermal fax paper, Polaroid film or similar technique. Operators are aware that specular reflections off some of these devices is possible, and that they may smoke or burn.
11. Pulsed lasers are aligned by firing single pulses when practical.
12. No intra-beam viewing is allowed unless specifically evaluated and approved by the LSO/DLSO. Intrabeam viewing is to be avoided by using cameras or fluorescent devices.
13. Normal laser hazard controls shall be restored when the alignment is completed. This includes enclosures, covers, beam blocks/barriers have been replaced, and affected interlocks checked for proper operation.

This document is to be reviewed in one year from the date of the OSP/IWS, or as conditions warrant, which ever is the shorter time period

Reviewed by:

____

LSO/DLSO Date

Approved/Reviewed/Revised by

____

Responsible Individual Date

Laser Beam Alignment

R. Timothy Hitchcock, CIH, CLSO
LightRay Consulting

Beam alignment requires work with an open beam and involves and involves directing the beam toward a series of reflective or partially reflective surfaces, such as mirrors or lenses, so that the beam follows some predetermined path. With respect to the laser, alignments may be internal or external.

Internal alignments are those occurring within the laser cavity or head and often place the worker at increased risk of electrical accidents as well as beam exposure. The need for internal alignments arises most often because of problems associated with beam mode or power.

External alignments are those that occur from the laser's end window to some terminal target. In between these two locations may be a number of optical components (optics) arrayed in more or less complex configurations. The need for external alignments occur because of reconfiguration of the optical setup or replacement of components either within the laser head or in the open beam path. External alignments may be optical table (benchtop), laser-to-fiberport, fiberport-to-fiberport, free-space transmission, beam-to-sensor (receiver), and laser therapy. The following practices are most applicable to external alignments on the optical table.

A. Suggested Alignment Practices

1. Perform alignments with a colleague or "buddy."

2. Review alignment operating procedures with your buddy.

3. Identify equipment and materials necessary to perform alignment.
    a. View beams indirectly: remote viewing, thermal paper, ceramic discs, IR/UV viewing scopes, paper business 3x5 inch cards, phosphor-viewing cards.
        - Make sure viewing cards have diffusing surfaces.
        - Cover the face of cards with specular surfaces with clear, matte-finish tape.
        - If fluorescent viewing cards need optical charging, have a UV lamp on hand.
        - Make sure conversion wavelengths are visible through protective eyewear.
    b. Tools, targets, beam stops/blocks, power meter/detector, beam profiling system, curtain, signage, caution tape.
    c. Make sure tools or items used in an around the beam path have non-reflective, diffusing surfaces at the wavelength(s) to be aligned.
    d. Personal protective equipment (PPE): alignment eyewear, operational power eyewear, face shields for scattered UV, skin protection as necessary.

4. Pay attention to housekeeping; make sure the immediate work area/benchtop/optical table is free from opportunistic specular reflectors that are not need for alignment (glass bottles, razor blades, forceps, screw drivers, optical posts, photographic paper, plastic, dye cells, etc.)

5. Remove jewelry from hands, wrist, ankles, ears, and neck that may be reflectors and are electrically conductive; if jewelry (e.g., wedding bands) is not easily removed, cover with multiple layers of electrical tape; remove tie tacks/clasps and neckties and materials in shirt pocket that may fall into the beam path.

6. Make sure that the beam shutter is closed or a beam block is in front of the end window. Make sure beam block is securely mounted.

7. Isolate and demarcate the area to avoid distractions and minimize the hazard to others.
   a. If Class-IV, open-beam system, make sure exterior warning signs/indicators are functioning.
   b. If embedded high-power laser, establish temporary laser controlled area.
      - Restricted to authorized and trained individuals.
      - Use beam blocking barrier or laser curtain to contain beam
      - Cover windows or viewing ports that are within the controlled area.
      - Use "Notice" and "Danger" signs per ANSI Z136.1.
   c. Confine the beam to the optical table or benchtop.

8. If the primary laser is optically pumped by another laser and alignment of the pump beam is necessary, block the primary beam to limit potential multi-wavelength exposure/eyewear concerns, align the pump beam then replace beam enclosure in the pump-to-laser beam path.

9. Prepare the beam delivery system: remove beam tubes or other parts of the protective housing as necessary, including extended sections that may be covered by beam tubes or bellows; check all optics (mirrors, lenses, filters, polarizers, expanders, etc.) and optomechanical components (base plates, post holders and fasteners, mirror mounts, etc.) ensuring they are currently aligned (for changes/additions to an existing alignment) and securely mounted.

10. If the beam path to be aligned is located in different rooms, locate a beam block in the beam path between the rooms, and align one room, then the other. If line of sight with buddies in other rooms is blocked, use two-way, real-time communications. Be patient at each step.

11. Use the minimum beam power/energy for as many alignment steps as possible or use a low-power, coaxial laser for path simulation.
   a. For CW lasers with adjustable power, adjust the power to a minimum stable level.
   b. For pulsed lasers, use single pulses and/or reduce pump power.
   c. For Q-switched lasers, turn off the Q-switch and use in the low-power, CW

mode

d. In some cases, power-reducing (e.g., neutral density) filters may be used during alignment.
e. Ensure that you have protective eyewear with the appropriate value of optical density for the beam power; using high OD eyewear that is suitable for normal operation with low-power, alignment beams is a formula for failure as is wearing low OD, alignment eyewear for high-power beams.

12. Proceed with system alignment:
    a. Wear laser protective eyewear to view diffuse reflections from viewing devices.
    b. Never view laser beams directly unless the scenario has been specifically approved by a knowledgeable laser safety officer (LSO).
    c. Perform the "rough" or coarse" alignment with the beam blocked.
    d. As you progress down the optical path, place beam blocks behind optics to be adjusted to stop errant (stray) beams.
    e. When using viewing aids to visualize the beam, reach into the beam path slowly and deliberately with the card slightly angled so you can see the diffuse reflection. Adjust the optic so that the beam strikes the card just in front of the surface of the component.
    f. If the beam path changes elevation (+Z), be aware of the increased potential for vertical reflections.
    g. Close the shutter or insert the beam block during adjustments; re-secure optics making sure components are properly located/adjusted.
    h. Be aware of the potential for errant reflections (stray beams) from components such as polarizers and dielectric mirrors. Check for stray beams at each step and again after completing all alignment steps.
    i. If the alignment has been performed at lower power or with a low-power collinear beam but final steps will be performed at operational power levels, be sure and change to the appropriate eyewear for the high-power beam.
    k. Communicate with your buddy at all times (e.g., during change of process step or before removal of protective eyewear.

13. Restore the system to normal operational mode (pay attention to the protective housing, interlock switches, and shutters) and verify normal operation.